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WEB-BASED GETINGE HS 66 STERILIZER MACHINE EXPERT SYSTEM USING BACKWARD CHAINING METHOD

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Abstract

Sterilization of medical equipment is essential for preventing nosocomial infections in healthcare facilities. The Getinge HS 66 autoclave used at Dr. Soediran Mangun Sumarso Regional Hospital requires fast and accurate fault diagnosis to maintain reliable operation, yet less experienced technicians often face difficulties in identifying equipment malfunctions independently. This study develops a web-based expert system using a backward chaining inference method to support autoclave fault diagnosis based on observable symptoms. The knowledge base was constructed through field observations, expert interviews, and literature review, comprising 20 fault types, 71 symptoms, and 72 corrective solutions. System validation was conducted using real maintenance cases and expert evaluations, covering all defined fault categories, and achieved 100% diagnostic accuracy and solution recommendation accuracy within the testing scope. User acceptance evaluation involving 34 electromedical technicians produced mean scores above 4.0 on a five-point Likert scale, with the highest score (mean = 4.500) indicating overall system effectiveness and efficiency. These results demonstrate that the proposed expert system is technically reliable and well accepted as a practical decision-support tool for autoclave maintenance.

Keywords : Expert System, Getinge HS 66 Autoclave, Backward Chaining, Medical Equipment Maintenance

Abstrak

Sterilisasi alat medis berperan penting dalam pencegahan infeksi nosokomial di fasilitas pelayanan kesehatan. Autoclave Getinge HS 66 yang digunakan di RSUD Dr. Soediran Mangun Sumarso memerlukan proses diagnosis kerusakan yang cepat dan akurat agar operasional tetap optimal. Namun, teknisi dengan pengalaman terbatas sering mengalami kesulitan dalam mengidentifikasi kerusakan alat secara mandiri. Penelitian ini mengembangkan sistem pakar berbasis web menggunakan metode inferensi backward chaining untuk membantu diagnosis kerusakan autoclave berdasarkan gejala yang diamati pengguna. Basis pengetahuan disusun melalui observasi lapangan, wawancara teknisi elektromedik, dan studi literatur, mencakup 20 jenis kerusakan, 71 gejala, dan 72 solusi. Validasi sistem dilakukan menggunakan skenario kerusakan nyata dari data pemeliharaan dan evaluasi pakar, dan menunjukkan akurasi diagnosis serta ketepatan rekomendasi solusi sebesar 100% dalam ruang lingkup pengujian. Evaluasi kuesioner terhadap 34 teknisi elektromedik menghasilkan nilai rerata di atas 4,0 pada seluruh indikator, dengan skor tertinggi 4,500 pada aspek efektivitas dan efisiensi sistem. Hasil ini menunjukkan bahwa sistem pakar yang dikembangkan andal secara teknis dan diterima dengan sangat baik oleh pengguna.

Kata kunci : Sistem Pakar, Autoclave Getinge HS 66, Backward Chaining, Pemeliharaan Peralatan Medis

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1. INTRODUCTION

Optimal healthcare delivery relies heavily on the availability of competent human resources, particularly those possessing strong cognitive and motor skills, to ensure high-quality medical services [1], [2]. In the context of infection prevention and control, medical personnel generally have adequate knowledge of pathogens and antibiotic usage; however, gaps often remain in their understanding, consistency, or attention to proper disinfection and sterilization procedures for medical equipment [3], [4], [5]. Sterilization is a critical process intended to eliminate all disease-causing microorganisms, including resistant bacterial spores, while preserving the physical and chemical integrity of medical devices [6], [7], [8]. Following clinical use, medical instruments may become contaminated with various microorganisms such as *Staphylococcus* spp., *Micrococcus* spp., diphtheroids, *Bacillus* spp., Gram-negative bacteria, fungi, and yeast [9], [10].

The Indonesian government has issued regulations concerning hospital environmental health, stipulating that microbial contamination levels must not exceed the allowable threshold of 0 CFU/mL[11], [12], [13]. . Among available sterilization techniques, moist heat sterilization using an autoclave is widely recommended due to its proven effectiveness in rapidly eliminating pathogenic microorganisms at elevated temperatures. Previous studies have demonstrated that steam sterilization in healthcare facilities can achieve optimal results when procedures are implemented correctly and in compliance with established standards [14].

At Dr. Soediran Mangun Sumarso Hospital in Wonogiri Regency, medical device sterilization is performed using a Getinge HS 66 autoclave. Despite its reliability, this equipment is susceptible to damage if routine maintenance is not properly conducted. Ideally, maintenance and repair activities should be handled by in-house electromedical technicians; however, when limitations in expertise, experience, or facilities arise, external service providers may be involved in accordance with applicable regulations [15]. Such limitations often stem from insufficient familiarity with specific equipment models or inadequate diagnostic experience among technicians.

In Indonesia, approximately 551 Getinge autoclave units are currently in operation, including 112 HS 66 units distributed across hospitals and clinics nationwide. This widespread use highlights the critical role of autoclaves in supporting infection control and patient safety. Consequently, a reliable system capable of detecting equipment malfunctions quickly and accurately is essential to maintain uninterrupted and optimal healthcare services.

To address this challenge, a solution is required that can bridge the knowledge gap between novice electromedical technicians and experienced experts in diagnosing medical equipment failures [16]. One promising approach is the development of an expert system that emulates the reasoning process of human experts. Such a system can assist technicians in identifying faults in medical devices, including autoclaves, and recommend appropriate corrective actions [17]. In this study, the backward chaining inference method is employed, as it enables the system to start from observable symptoms reported by users and logically infer the most probable damaged components [18].

2. LITERATURE REVIEW

Several previous studies have investigated the performance, modification, and design of autoclave systems from technical and operational perspectives. The study entitled *"Performance Qualification of Industrial Steam Sterilizer (Autoclave)"* [6], was conducted through two main stages. The first stage focused on ensuring that the sterilizer operated under controlled conditions, while the second stage evaluated the effectiveness of the sterilization process. Heat penetration testing was carried out using a predetermined maximum load, and temperature distribution was monitored using external temperature sensors to map heat uniformity during sterilization. In addition, biological indicators were employed to verify the effectiveness of the sterilization process in eliminating microorganisms.

Another study, *"Autoclave Modification Based on Atmega328 (Temperature)"* [19], proposed a modified autoclave system and compared its performance with conventional measuring instruments, including a thermometer, timer, and stopwatch. Sterilization testing was conducted using autoclave tape as an indicator. The results showed a temperature correction value of 0.5 and a timer correction value of 3.3 seconds for a 900-second measurement. The sterilization trials demonstrated effective sterilization times ranging from 15 to 20 minutes. Overall, the study concluded that the modified autoclave exhibited relatively small measurement deviations and was capable of

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achieving effective sterilization within a practical time frame.

Similarly, the research entitled *"Autoclave Design Using a DS18B20 Temperature Sensor with Arduino-Based Relay Control"* [20], focused on the development of an autoclave system utilizing a DS18B20 temperature sensor integrated with Arduino Uno-based relay control. The sensor measured the internal temperature of the sterilizer, while users were able to set the desired temperature and sterilization duration, which were displayed on an LCD interface. Performance testing indicated that medical instruments could be considered sterile when exposed to a temperature of 121 °C for 10–15 minutes. Sterilization effectiveness was assessed using autoclave tape paper, where a light brown color indicated insufficient sterilization, while a blackish-brown color signified successful sterilization.

Although these studies provide valuable contributions in terms of autoclave performance evaluation, hardware modification, and temperature-based control systems, they primarily focus on the technical operation and effectiveness of the sterilization process. None of the previous works explicitly address the problem of diagnostic support for autoclave malfunction or the knowledge gap faced by electromedical technicians when identifying equipment failures. Moreover, the existing studies do not incorporate intelligent reasoning mechanisms to assist in fault diagnosis and decision-making.

In contrast, the present study positions itself by emphasizing the development of an expert system for diagnosing faults in autoclave equipment, particularly the Getinge HS 66. By applying a backward chaining inference method, this research offers a structured knowledge-based approach that enables technicians to identify damaged components based on observable symptoms. The main advantage of this study lies in its ability to translate expert knowledge into a practical diagnostic tool, thereby improving maintenance efficiency, reducing dependency on expert technicians, and enhancing the reliability of sterilization services. This focus on intelligent fault diagnosis represents the key novelty and contribution of the proposed research compared to previous autoclave-related studies.

3. RESEARCH METHODOLOGY

3.1 Data Collection

Data collection was conducted through systematic and structured procedures to obtain accurate, valid, and reliable information aligned with the research objectives [21]. Multiple complementary techniques were employed to ensure data completeness and credibility. The selection of instruments was based on the characteristics of diagnostic variables and the functional requirements of the expert system under development [22], [23].

The literature review focused on error-code documentation from the Getinge HS 66 technical manual, relevant scientific publications addressing autoclave malfunction analysis, and supporting technical records, as illustrated in Figure 1. This step enabled the identification of standardized fault symptoms, operational patterns, and common failure modes. Direct observation was carried out on the Getinge HS 66 autoclave unit at RSUD Kabupaten Wonogiri, emphasizing process printouts, LCD error messages, and physical inspections of machine components. These observations provided real-world malfunction cases that were essential for constructing a representative knowledge base.

In addition, expert interviews were conducted with certified electromedical technicians responsible for autoclave maintenance. Structured interviews were used to capture expert knowledge related to frequent failures, causal relationships, and recommended troubleshooting actions. This expert-derived knowledge formed the core of the rule base implemented within the backward chaining inference mechanism.

Figure 1. Data Collection

3.2 Research Design

The primary research materials consisted of documented malfunction cases of the Getinge HS 66 autoclave obtained from maintenance records at RSUD Kabupaten Wonogiri. Supplementary materials included expert knowledge acquired through interviews with experienced technicians. These datasets constituted the foundation for developing the system's knowledge base and rule structures used in the backward chaining inference process.

The study utilized both hardware and software

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resources to support system development, deployment, and evaluation [24]. Hardware components included a personal computer or laptop for development and analysis, as well as a local server environment to facilitate online testing and system deployment.

The software environment comprised Laragon (Apache and MySQL) as the local web server, PHP as the backend programming language, and HTML, CSS, and JavaScript for user interface development. A web browser was used for system access and evaluation, while Visual Studio Code served as the primary code editor throughout the development process.

The research followed a structured workflow to ensure systematic development of the expert system. The stages included: conducting a literature review on expert systems, backward chaining, and autoclave malfunctions; collecting malfunction data and expert insights; designing the system architecture, knowledge base, and rule base; implementing the system using web-based technologies; testing and validating the system using real diagnostic cases; and evaluating system performance in terms of accuracy and reliability.

3.3 System Design

The system design phase defined the overall architecture, inference mechanism, and technical components of the expert system. A backward chaining inference strategy was adopted, where the diagnostic process begins with a hypothesis regarding a possible malfunction and traces backward to verify supporting evidence based on observed symptoms.

3.3.1 Block Diagram

The system block diagram shown in Figure 2 illustrates the interaction among the core components of the expert system.

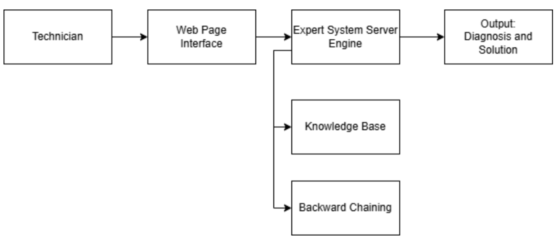

Figure 2. System Block Diagram

The diagram depicts how user-input symptoms related to the Getinge HS 66 autoclave are entered through a web-based interface and processed by the inference engine using the backward chaining method. The inference engine evaluates the input by matching it against the knowledge base to identify potential malfunctions and corresponding solutions. The diagnostic results and troubleshooting recommendations are then presented to the user. This block diagram provides a clear overview of the structured and efficient operation of the expert system.

3.3.2 System Flowchart

The flowchart Figure 3 visualizes the step- by-step logic applied throughout the diagnostic process. The workflow begins with user consultation, continues with symptom input, and proceeds to diagnostic reasoning using backward chaining. If a matching rule is found, the system outputs a diagnosis and solution; otherwise, the system advises the user to consult an expert. The flowchart facilitates implementation and subsequent testing.

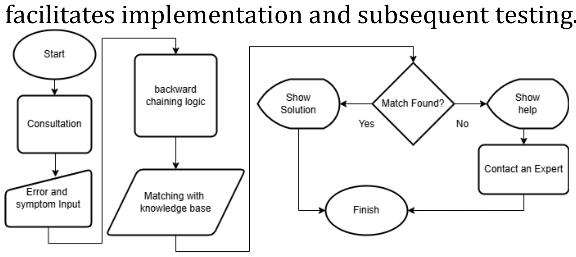

Figure 3. System Flowchart

The process begins with user consultation, followed by symptom input. The system then performs diagnostic reasoning using backward chaining to match the symptoms against the rule base. If a matching rule is identified, the system outputs the diagnosis and recommended solution. If no suitable rule is found, the system notifies the user and advises consultation with an expert technician. The flowchart clarifies the step-by-step workflow and facilitates system implementation and testing.

3.3.3 Database Design

The database schema Figure 4 consists of interconnected tables that represent malfunctions, solutions, and user accounts:

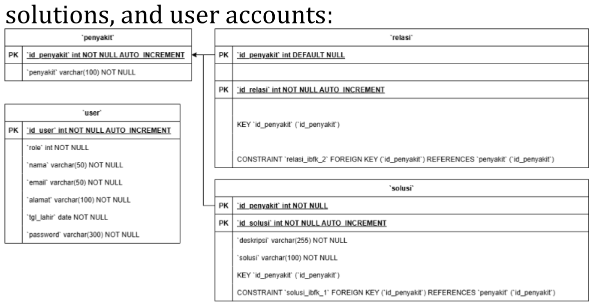

Figure 4. Database Schema

A. Malfunction Table: Stores malfunctioning categories with unique identifiers.
B. Relation Table : Connects malfunctions with their corresponding solutions using foreign key references.
C. Solution Table : Contains detailed

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troubleshooting steps mapped to specific malfunction cases.

D. User Table : Stores user information, including credentials and roles (admin, technician, expert).

This relational structure ensures efficient data retrieval and supports systematic backward chaining reasoning.

3.4 System Testing and Validation

System testing and validation were performed to evaluate functionality, accuracy, and reliability. The expert system was deployed within an online web server environment to simulate real operational conditions. Functional testing verified that all system features operated as intended, while error-handling tests assessed the robustness of the inference engine.

Validation was conducted by comparing system-generated diagnoses with expert assessments and actual malfunction cases. This comparison evaluated the consistency and correctness of the system's reasoning. The validation results provided a basis for system refinement prior to implementation at RSUD Kabupaten Wonogiri.

3.5 Example of Backward Chaining Inference Process

To enhance clarity, this section presents an illustrative example of the backward chaining inference applied in the expert system.

Assume the system hypothesizes a malfunction **"Steam Pressure Failure"**. To confirm this hypothesis, the inference engine checks whether the required symptoms are present, such as *low chamber pressure*, *incomplete sterilization cycle*, and *error code displayed on the LCD panel*. The user is prompted to confirm these symptoms. If all conditions are satisfied, the system concludes that the suspected malfunction is valid and outputs the corresponding diagnosis along with recommended corrective actions. Conceptually, the inference process can be summarized as follows:

1. Select a hypothesis (possible malfunction).
2. Identify symptoms required to support the hypothesis.
3. Verify the presence of these symptoms through user input.
4. If all symptoms are confirmed, conclude the diagnosis and present the solution.
5. If not, reject the hypothesis and evaluate alternative malfunctions.

This example demonstrates how backward chaining systematically traces observable symptoms to reach a reliable diagnostic conclusion, thereby improving user understanding of the system's reasoning process.

4. RESULTS AND DISCUSSION

4.1 Implementation of the Web-Based Expert System

The expert system developed in this study is designed to support fault diagnosis of the Getinge HS 66 autoclave using a backward chaining inference mechanism. The system was implemented as a web-based application consisting of three main functional modules: diagnostic consultation, knowledge-base management, and diagnostic reporting. The knowledge base was constructed from a combination of field observations, structured interviews with experienced electromedical technicians, and relevant documentation such as equipment manuals and LCD error code descriptions.

The knowledge representation is organized into four primary entities: faults, symptoms, solutions, and inference rules. Each fault is associated with a specific set of symptoms, which are traced backward by the inference engine to validate diagnostic hypotheses. The overall system interface and functional workflow are illustrated as follows.

The home page (Figure 5) provides a general overview of the system, including user instructions, a brief explanation of the backward chaining method, and frequently asked questions intended to support technician learning. A "Diagnose Now" navigation button directs users to the diagnostic process.

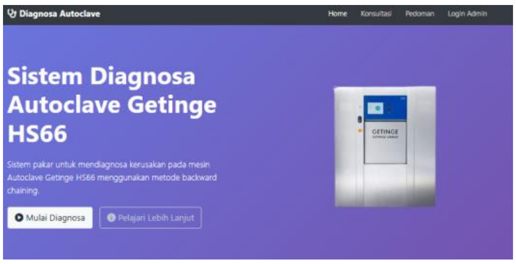

Figure 1. Home Page

The admin interface (Figure 6) supports full

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CRUD (Create, Read, Update, Delete) operations for faults, symptoms, solutions, and knowledge rules. Any updates made through this interface are stored in the database and reflected immediately in the system interface.

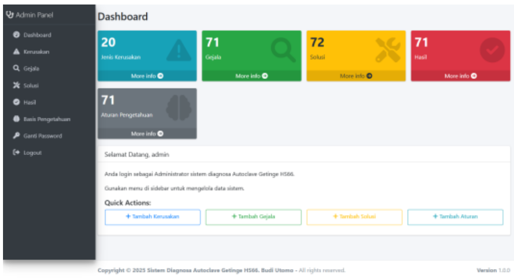

Figure 2. Admin interface.

During the diagnostic workflow (Figures 7–9), technicians select a fault category and respond to a series of yes/no questions related to observed symptoms. Based on these inputs, the system generates a diagnostic result that includes the most probable fault, a percentage-based confidence indication, and recommended corrective actions. If no suitable rule is satisfied, the system advises the user to consult an expert technician via an integrated contact link.

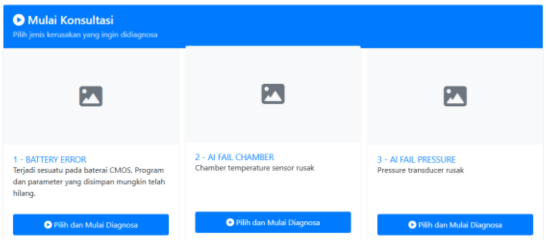

Figure 3. Fault Category

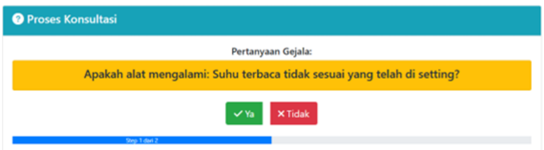

Figure 4. Symptom questions

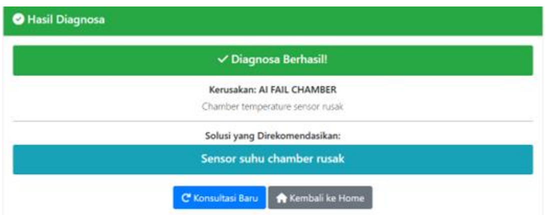

Figure 5. Result

4.2 Knowledge-Base Content

Table 1 Faults: A catalog of autoclave error types identified during observation and technician interviews (coded E1–E20), each with a short descriptive summary and typical causes.

Table 1. Faults

Error Code	Error Name	Description
E1	BATTERY ERROR	Something happened to the CMOS battery.
E2	AI FAIL CHAMBER	Chamber temperature sensor is damaged
E3	AI FAIL PRESSURE	Pressure transducer is damaged
...	...	...
E20	POST. TIMEOUT	Post-treatment processing exceeds the completion time limit.

Table 2 Symptoms: A list of observable indicators (coded G1–G71) derived from process printouts, LCD messages, and physical inspection notes.

Table 2. Symptoms

Symptom Code	Symptom Name
G1	Battery is not charging/drops
G2	The battery compartment looks dirty.
G3	The temperature reading does not match the setting.
...	....
G71	Slow pressure reduction

Table 3 Solutions, Corrective procedures (coded S1–S72) that provide step-by-step troubleshooting guidance mapped to specific

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faults.

Table 3. Solutions

Solution Code	Solution Name
S1	replace the battery if it is damaged.
S2	Replace the battery compartment if it is damaged or corroded.
S3	Replace the temperature sensor if it is damaged.
...	....
S72	clean the slow exhaust needle valve or outlet hole

Table 4 Knowledge Rules: If–then rules (A1–A20) that link combinations of symptoms to faults and associated solutions (e.g., "If G1 AND G2 then E1 with S1,S2").

Table 4. Knowledge

Rule	Symptom	Fault	Solution
A1	G1, G2	E1	S1, S2
A2	G3, G4	E2	S3, S4
A3	G5	E3	S5
...	...	...	...
A20	G67, G68, G69, G70, G71	E20	S68, S69, S70, S S72

4.3 Testing, Validation, and Performance Results

4.3.1 Functional and Consistency Testing

Functional testing was performed across all user roles and system features: authentication, knowledge-base CRUD, diagnostic consultation, and result rendering. Test scenarios were derived from real maintenance cases. Synchronization between admin edits and technician views remained consistent in real time, indicating reliable database integration and UI update behavior.

4.3.2 Diagnostic Accuracy and Validation

Validation compared system outputs against expert judgments using a set of predefined real-case scenarios. Across the tested scenarios (covering the 20 defined fault types), the system produced diagnostic conclusions that matched expert diagnoses in the validation set. The system also returned appropriate ordered solution steps corresponding to expert recommendations. On the evaluated dataset, the system reported:

Diagnostic match with expert decision: 100%. Solution recommendation matches expert guidance: 100%. These results indicate that the implemented inference rules and knowledge representation are internally consistent with the expert knowledge captured during data collection.

4.4 Discussion

4.4.1 Effectiveness of the Knowledge Base

The knowledge base proved effective in supporting backward chaining reasoning. The representation of 20 faults, 71 symptoms, and 72 solutions governed by 20 rule sets provides sufficient granularity to model common malfunction patterns of the Getinge HS 66 autoclave. Multi-symptom rules—such as those addressing gasket failure—reduce reliance on single indicators and improve diagnostic robustness. The high agreement with expert validation confirms strong internal consistency between the encoded knowledge and automated inference.

4.4.2 Backward-Chaining Workflow Efficiency

The backward chaining mechanism functioned as intended by initiating diagnosis from candidate fault hypotheses and requesting supporting evidence through symptom confirmation. This goal-driven approach mirrors expert diagnostic reasoning and supports novice technicians through structured inquiry. Simulated scenarios demonstrated correct rule activation, incremental evidence validation, and accurate delivery of solution packages.

4.4.3 Coverage, Maintainability, and Scalability

The modular database structure and web-based administration facilitate straightforward maintenance and future expansion. New faults, symptoms, or solutions can be incorporated without

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altering the core system logic. While the current coverage addresses common operational issues, rare or newly emerging faults would require additional data acquisition and rule formulation.

4.4.4 Critical Discussion on Diagnostic Accuracy and Limitations

Although the system achieved 100% agreement with expert diagnoses during validation, this result must be interpreted within the scope of the testing conditions. The validation dataset was derived from a single institution and involved experts who contributed to the knowledge elicitation process. Consequently, the reported accuracy reflects internal consistency rather than universal generalizability.

Potential diagnostic errors may arise if symptom data are incomplete, incorrectly interpreted, or inaccurately input by users. Because the inference mechanism relies on deterministic rules, missing or erroneous symptom confirmation can lead to incorrect hypothesis rejection or misclassification. This limitation highlights the importance of accurate symptom observation and user training, as well as the need for enhanced mechanisms to handle uncertainty and partial evidence.

4.4.5 User Evaluation Based on Questionnaire

User perception of the system was evaluated through a structured questionnaire involving 34 electromedical technicians from various institutions. The questionnaire employed a five-point Likert scale (1 = strongly disagree to 5 = strongly agree) to assess system effectiveness, usability, clarity, interface design, and overall efficiency.

Table 5. Questionnaire Results

No.	Question (actual)	Number of Respondents (valid)	Mean Score	Interpretation
1	Q1	34	4.324	Strongly Agree
2	Q2	34	4.412	Strongly Agree
3	Q3	34	4.471	Strongly Agree
4	Q4	34	4.353	Strongly Agree
5	Q5	34	4.500	Strongly Agree

The results, summarized in Table 4.8, show that all evaluated indicators achieved mean scores above 4.0, indicating very high user acceptance. The effectiveness of the system in assisting fault identification received a mean score of 4.324. Ease of use and menu clarity scored 4.412, while information clarity achieved the highest score of 4.471. Interface design received a mean score of 4.353, and overall system effectiveness and efficiency reached 4.500.

These findings demonstrate that users perceive the expert system as highly effective, intuitive, and supportive in real diagnostic contexts. Qualitative feedback further suggested improvements in interface interactivity, visual aesthetics, and language simplification to accommodate technicians with varying experience levels. Several respondents also recommended extending the system to diagnose other types of medical equipment. Overall, the questionnaire results reinforce the system's practical relevance and potential for broader adoption.

4.5 Summary of Key Findings

This study successfully developed a web-based expert system for diagnosing Getinge HS 66 autoclave malfunctions using a backward chaining approach. Within the defined validation scope, the system demonstrated full agreement with expert diagnoses and solution recommendations. User evaluations further confirmed high acceptance and perceived effectiveness. While the system architecture supports maintainability and expansion, future work should focus on external validation, uncertainty modeling, and automated symptom acquisition to enhance diagnostic robustness and generalizability.

5. CONCLUSION

This study successfully developed a web-based expert system using a backward chaining inference

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method to diagnose malfunctions in the Getinge HS 66 autoclave. The system was able to replicate expert reasoning through structured IF–THEN rules, enabling systematic symptom verification and automatic generation of appropriate corrective recommendations. Within the defined validation scope, the system achieved 100% agreement with expert diagnoses and solution recommendations, supported by stable functional performance and full synchronization of all system features. These results indicate that the proposed expert system is reliable as a decision-support tool for preliminary autoclave fault diagnosis, particularly in routine maintenance activities.

User evaluation further confirmed the practical effectiveness of the system. Based on questionnaire responses from 34 electromedical technicians, all assessment indicators obtained mean scores above 4.0 on a five-point Likert scale, reflecting very high user acceptance. The highest score was recorded for overall system effectiveness and efficiency (mean = 4.500), followed by information clarity (mean = 4.471) and ease of use (mean = 4.412). These findings demonstrate that the system is not only technically accurate but also well received by users, especially novice technicians. Future work should focus on expanding validation across multiple institutions and incorporating probabilistic reasoning to enhance robustness when dealing with incomplete or uncertain symptom data.

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